

EVALUATION PROGRAM
for
SECONDARY SPACECRAFT CELLS

INITIAL EVALUATION TESTS
OF
EAGLE - PICHER INDUSTRIES, INCORPORATED
20.0 AMPERE-HOUR NICKEL-CADMIUM SPACECRAFT CELLS

prepared for
GODDARD SPACE FLIGHT CENTER

CONTRACT S-23404-G

QUALITY EVALUATION AND ENGINEERING LABORATORY
NAD CRANE, INDIANA

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DEPARTMENT OF THE NAVY
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CRANE, INDIANA 47522

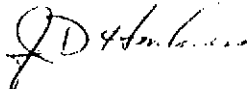
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OF
EAGLE-PICHER INDUSTRIES, INCORPORATED
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QEEL/C 74-228

25 MARCH 1974

PREPARED BY



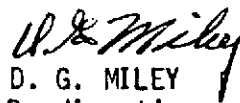
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Enclosure (1)

REPORT BRIEF
EAGLE-PICHER INDUSTRIES, INCORPORATED
20.0 AMPERE-HOUR NICKEL-CADMIUM SPACECRAFT CELLS

Ref: (a) NASA P.O. S-23404-G
(b) Initial Evaluation Test Procedure for Nickel-Cadmium
Sealed Space Cells: NAD 3053-TP324, 10 Apr 1973

I. TEST ASSIGNMENT BRIEF

A. The purpose of this evaluation test program is to insure that all cells put into the life cycle program are of high quality by the screening of cells found to have electrolyte leakage, internal shorts, low capacity, or inability of any cell to recover its open circuit voltage above 1.150 volts during the internal short test.

B. The 18 cells were manufactured for the National Aeronautics and Space Administration, Goddard Space Flight Center, under the Process Variable Study Program, Contract NAS 5-21159, by Eagle-Picher Industries, Incorporated, Joplin, Missouri. These parametric cells are rated at 20.0 ampere-hours, contain double ceramic seals, and are designated as 3-cell groups as follows:

<u>Group</u>	<u>Designation</u>
1	Low Active Material Loading
2	Decrease in Formation Cycles
3	Increase in Formation Cycles
4	Vacuum Dry after Final Wash
5	High Active Material Loading
6	Complete Discharge of Electrodes During Electrochemical Cleaning

The cells were received with pressure gauges and the testing was funded in accordance with reference (a).

C. Test limits specify those values in which a cell is to be terminated from a particular charge or discharge. Requirements are referred to as normally expected value based on past performance of aerospace nickel-cadmium cells with demonstrated life characteristics. A requirement does not constitute a limit for discontinuance from test.

II. SUMMARY OF RESULTS

A. The cells of Group 1 had a high internal resistance (excess of 0.16 ohm), at the beginning of test and one cell, S/N 15, was not tested because of this resistance (310 milliohms).

i (a)

B. The capacity of the cells ranged from 13.8 to 30.5 ampere-hours during the three capacity tests with Group 1 having the lowest capacity and Group 5 having the highest.

C. Cells from Groups 2, 4 and 6 were removed from charge because of high pressure (100 psia), during capacity tests 2 and 3, and one cell from Group 2 was also removed during the initial charge because of high pressure.

D. Cells of Groups 1, 2, 4 and 5 exceeded the voltage requirement of 1.480 volts during capacity test 3 and one cell from Group 4 exceeded this requirement during the second capacity test. Only those cells of Group 2 exceeded 1.48 volts at the end of charge.

E. One cell from Group 1 and all cells from Groups 4, 5 and 6 did not meet the minimum requirement of 55 percent capacity out of capacity in during the 20°C charge efficiency test.

F. Only those cells of Group 3 did not exceed 1.520 volts during the 0°C overcharge test and cells from Groups 2 and 6 were terminated from charge due to high pressure. Group 1 cells, and two cells from Group 6 did not deliver 20.0 ampere-hours of capacity out following charge.

G. During the 35°C overcharge test, all the cells of Group 2 and two cells each of Groups 4 and 6 were terminated from charge due to high pressure. Also, cells from Group 1 did not meet the minimum requirement of 55 percent of capacity out as was obtained during the third capacity test.

H. All cells of Group 1, one cell from Group 3, and two cells from Group 6 exceeded 1.55 volts immediately after start of charge during the pressure versus capacity test. These cells were allowed to continue on charge until a pressure of 20 psia was reached. The other cells reached a pressure of 20 psia before the voltage limit (1.550 volts), except one cell each from Groups 2, 4 and 5 in which the pressure and voltage limit were reached at the same time. There was no pressure decay exhibited by any cells during the open-circuit stand portion of the test. The cells that exceeded 1.550 volts at the beginning of charge delivered less than 10.0 ampere-hours out during the discharge portion of the test and only two other cells, one each from Groups 4 and 6, delivered less than 30.0 ampere-hours.

I. One cell, S/N 13, of Group 1 had a leak at its negative terminal following completion of test.

J. One cell, S/N 15, of Group 1 was returned to the Goddard Space Flight Center for metallurgical analysis. Results of this analysis showed that the saddle-to-tab weld areas were devoid of a weld zone; but one area did show some squeezing of the saddle.

III. RECOMMENDATIONS

A. It is recommended that these cells not receive further testing, since the results of this acceptance test indicate the manufacturing technique used in producing the cells from Group 1, one of which showed no saddle-to-tab welds, was probably used in the manufacture of the other cell groups.

RESULTS OF INITIAL EVALUATION TESTS
OF
20.0 AMPERE-HOUR NICKEL-CADMIUM SPACECRAFT CELLS
MANUFACTURED BY
EAGLE-PICHER INDUSTRIES, INCORPORATED

I. TEST CONDITIONS AND PROCEDURE

A. All evaluation tests were performed at room ambient (RA) pressure and temperature ($25^{\circ} \pm 2^{\circ}\text{C}$) unless otherwise specified, and in accordance with reference (b) and consisted of the following:

1. Phenolphthalein leak tests (2).
2. Three capacity tests, third at 20°C ; with internal resistance measurements during second charge/discharge.
3. Internal short test.
4. Charge efficiency test, 20°C .
5. Overcharge tests, 0°C and 35°C .
6. Pressure versus capacity test.

See Appendix I for summary of test procedure.

II. CELL IDENTIFICATION AND DESCRIPTION

A. The cells were identified by the manufacturer's serial numbers and placed in a pack configuration (Packs 507X and 508X) for testing. The serial numbers and Group designations are as follows:

<u>Group</u>	<u>Serial Numbers</u>	<u>Designation</u>
1	13-15	Low Active Material Loading
2	17, 18, 20	Decrease in Formation Cycles
3	21, 23, 24	Increase in Formation Cycles
4	25, 27, 28	Vacuum Drying after Final Wash
5	29-31	High Active Material Loading
6	33, 34, 36	Complete Discharge of Electrodes During Electrochemical Cleaning

B. The 20.0 ampere-hour cell is rectangular with average physical dimensions as follows:

<u>Height (in.)</u>	<u>Length (in.)</u>	<u>Width (in.)</u>
7.058	0.896	2.987

The weight of the cells varied due to the different variables. These are listed in Table I.

C. The cell containers and covers are made of stainless steel. The positive and negative terminals are insulated from the cell cover by ceramic seals and protrude through the cover as solder-type terminals.

III. RESULTS--The following was condensed from Tables I through V:

A. Leak Tests--Cell, S/N 13, indicated leakage at its negative terminal following test.

B. Average Capacity (ampere-hours, AH):

<u>Type of Charge</u>	<u>Group*</u>	<u>1***</u>	<u>2</u>	<u>3</u>	<u>4</u>	<u>5</u>	<u>6</u>
C/20, 28 hours, RA**		16.2	28.6	22.7	27.1	29.2	22.6
C/10, 24 hours, RA**		14.2	26.9	21.3	28.3	30.1	23.2
C/10, 24 hours, 20°C**		15.9	26.3	24.6	26.9	28.7	21.4

*AH out.

**Cells from Groups 2, 4 and 6 were removed from charge, because of high pressure, during capacity tests 2 and 3, and one cell from Group 2 was also removed during the initial charge.

Cells from Groups 1, 2, 4 and 5 exceeded the requirement of 1.480 volts during capacity test 3 and one cell from Group 4 exceeded 1.480 volts during the second capacity test. Group 2 cells exceeded 1.480 volts at the end of charge.

***Two cells only.

C. Average Internal Resistance Measurements (milliohm):

<u>Measurement Taken</u>	<u>Group</u>	<u>1</u>	<u>2</u>	<u>3</u>	<u>4</u>	<u>5</u>	<u>6</u>
30 min. before end of charge (Cycle 1)		5.6	3.5	3.9	3.0	3.6	3.9
1 hr. after start of discharge (Cycle 2)		10.5	3.2	3.6	3.3	3.2	4.0
2 hrs. after start of discharge (Cycle 2)		15.0	3.0	4.1	3.2	3.4	4.2

D. All cell voltages exceeded 1.200 volts after 24 hours following a 16-hour short period.

E. Average capacity out during the 20°C charge efficiency test was as follows:

<u>Group</u>	<u>1*</u>	<u>2</u>	<u>3</u>	<u>4*</u>	<u>5*</u>	<u>6*</u>
AH Out	5.4	6.1	6.6	4.3	4.9	5.1

*All cells from Groups 4, 5 and 6 and one cell from Group 1 failed to deliver the minimum requirement of 55 percent capacity out of capacity in.

F. Average capacity out during the 0°C overcharge test was as follows:

<u>Group</u>	<u>1</u>	<u>2**</u>	<u>3*</u>	<u>4</u>	<u>5</u>	<u>6**</u>
AH Out	13.7	24.9	24.0	26.9	28.0	19.5

*Only cells from this group did not exceed the 1.520 voltage requirement during charge.

**Cells from these groups were terminated from charge due to high pressure.

G. Average capacity out during the 35°C overcharge test was as follows:

<u>Group</u>	<u>1**</u>	<u>2*</u>	<u>3</u>	<u>4*</u>	<u>5</u>	<u>6*</u>
AH Out	7.1	22.2	14.0	17.8	24.0	14.4

*Cells from these groups were terminated from charge due to high pressure.

**Cells did not meet the minimum requirement of 55 percent of capacity out as was obtained during the third capacity test.

II. Average capacity in and out during the pressure versus capacity test is as follows:

<u>Group</u>	<u>1*</u>	<u>2**</u>	<u>3*</u>	<u>4**</u>	<u>5**</u>	<u>6*</u>
AH In to 20 psia	9.3	36.0	25.7	31.6	36.7	15.5
AH Out	2.0	28.5	19.1	24.1	29.2	9.9

*Some cells from these groups exceeded 1.550 volts at the start of charge. Allowed to charge to 20 psia, these cells delivered less than 10 AH out on discharge.

**One cell from each of these groups reached pressure and voltage limit at the same time.

I. One cell, S/N 15, of Group 1 was returned to the Goddard Space Flight Center for metallurgical analysis. Results of this analysis showed that the saddle-to-tab weld areas were devoid of a weld zone; but one area did show some squeezing of the saddle (Figure 1).

APPENDIX I

I. TEST PROCEDURE

A. Phenolphthalein Leak Tests:

1. This test is a determination of the condition of the welds and ceramic seals on receipt of the cells and following the last discharge of the cells (Cycle #7).

2. The cells were initially checked with a one-half of one percent phenolphthalein solution applied with a cotton swab and then placed in a vacuum chamber and exposed to a vacuum of 40 microns of mercury or less for 24 hours. Upon removal they were rechecked for leaks and then received a final check following test completion. The requirement is no red or pink discoloration which indicates a leak.

B. Capacity Tests:

1. The capacity test is a determination of the cells' capacity at the C/2 discharge rate to 0.75 volt per cell, where C is the manufacturer's rated capacity. This type discharge follows all charges of this evaluation test.

2. The charges for the capacity tests are as follows:

a. C/20, 48 hours, room ambient (RA), Cycle 0, with a test limit of 1.52 volts or pressure of 100 psia.

b. C/10, 24 hours, RA, Cycle 1, with a test limit of 1.52 volts or 100 psia pressure and a requirement of maximum voltage (1.48) or pressure (65 psia).

c. C/10, 24 hours, 20°C, Cycle 2, with the same limits and requirements as the charge of Cycle 1.

C. Internal Resistance:

1. Measurement are taken across the cell terminals 1/2 hour before the end-of-charge (EOC) on Cycle 1 and 1 and 2 hours after the start-of-discharge of Cycle 2. These measurements were made with a Hewlett-Packard milliohmmeter (Model 4328A).

D. Internal Short Test:

1. This test is a means of detecting slight shorting conditions which may exist because of imperfections in the insulating materials, or damage to element in handling or assembly.

2. Following completion of the third capacity discharge, the cells are shunted with a 0.5-ohm, 3-watt resistor for 16 hours. At the end of 16 hours the resistors are removed and the cells stand on open-circuit-voltage (OCV) for 24 hours. A minimum voltage of 1.15 is required at the end of 24 hours.

E. Charge Efficiency Test, 20°C:

1. This test is a measurement of the cells' charge efficiency when charged at a low current rate.

2. The cells are charged at C/40 for 20 hours with a test limit of 1.52 volts or 100 psia pressure. They are then discharged and the requirement is that the minimum capacity out equals 55 percent of capacity in during the preceding charge.

F. Overcharge Test #1, 0°C:

1. The purpose of this test is to determine the degree to which the cells will maintain a balanced voltage, and to determine the cells' capability to be overcharged without overcharging the negative electrode.

2. The cells are charged at C/20 for 60 hours. The test limits are cell voltages of 1.56 or greater for a continuous time period of 2 hours or pressures of 100 psia. The requirement is a voltage of 1.520 or a pressure of 65 psia. The cells are then discharged and 85 percent capacity out of that obtained in Cycle 3 is required.

G. Overcharge Test #2, 35°C:

1. This test is a measurement of the cells' capacity at a higher temperature when compared to its capacity at 20°C. This test also determines the cells' capability of reaching a point of pressure equilibrium; oxygen recombination at the negative plate at the same rate it is being generated at the positive plate.

2. The cells are charged at C/10 for 24 hours with a test limit of 1.52 volts or 100 psia pressure and a requirement of 1.45 volts or 65 psia pressure. The cells are then discharged with a

requirement that capacity out equals 55 percent capacity out as obtained in Cycle 3.

H. Pressure Versus Capacity Test:

1. The purpose of this test is to determine the capacity to a pressure and the pressure decay during charge and open circuit stand respectively.

2. Each cell is charged at C/2 to either a pressure of 20 psia or a voltage of 1.550. Recordings are taken on each cell when it reaches 5, 10, 15 and 20 psia pressure. The cells then stand OCV for 1 hour with 30-minute recordings and then are discharged, shorted out and leak tested.

Figure 1

Figure 1. Cross-section of saddle-to-tab in the weld area, 20 Ampere-hour cell S/N 15

25 X

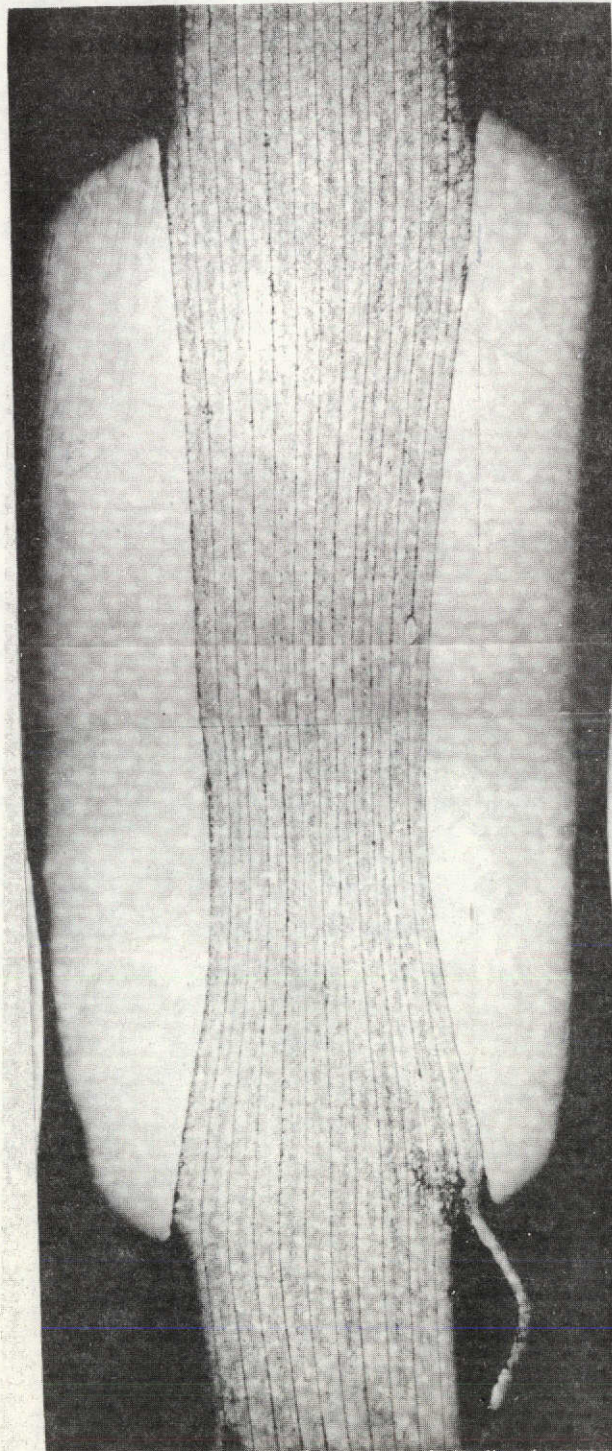


TABLE I

QFEEL/C 74-228

TABLE II
Capacity Data

SERIAL NUMBER	Capacity Test 1 ***						Capacity Test 2						Capacity Test 3 (20°C)					
	END-OF-CHARGE			END-OF-DISCHARGE			END-OF-CHARGE			END-OF-DISCHARGE			END-OF-CHARGE			END-OF-DISCHARGE		
	CELL (Volts)	AUX ELECT (Volts)	PRESS (PSIA)	CAPAC- ITY (ah)	AUX ELECT (Volts)	PRESS (PSIA)	CELL (Volts)	AUX ELECT (Volts)	PRESS (PSIA)	CAPAC- ITY (ah)	AUX ELECT (Volts)	PRESS (PSIA)	CELL (Volts)	AUX ELECT (Volts)	PRESS (PSIA)	CAPAC- ITY (ah)	AUX ELECT (Volts)	PRESS (PSIA)
13	1.421	N/A	35	16.0	N/A	18	1.429	N/A	59	14.6	N/A	22	1.461**	N/A	37	15.7	N/A	13
14	1.414		41	16.3		21	1.426		66	13.8		27	1.454**		45	16.1		21
15																		
17	1.445		77	29.3		35	1.458		100*	26.7		16	1.487**		100*	26.1		42
18	1.444		80	28.6		42	1.454		108*	26.4		17	1.485**		100*	25.7		42
20	1.446		100*	28.0		39	1.459		115*	27.7		14	1.493**		100*	27.1		43
21	1.408		20	22.3		5	1.412		36	20.8		6	1.441		17	24.0		4
23	1.409		18	22.7		5	1.411		36	21.2		6	1.443		18	24.8		5
24	1.412		17	23.1		5	1.416		25	21.8		4	1.447		14	25.1		4
25	N.A.		63	27.3		10	1.479**		100*	28.5		35	1.471**		80	28.5		35
27	N.A.		71	26.9		13	1.461		100*	28.3		37	1.461**		100*	26.3		46
28	N.A.		71	27.1		13	1.461		100*	28.2		33	1.463**		100*	26.0		36
29	N.A.		21	29.2		4	1.453		48	29.8		14	1.461**		37	28.5		13
30	N.A.		21	29.2		5	1.452		40	30.5		13	1.462**		30	29.3		12
31	N.A.		22	29.3		5	1.450		48	30.1		18	1.459**		37	28.5		13
33	N.A.		32	23.5		5	1.448		68	24.5		20	1.454		66	23.1		25
34	N.A.		44	21.9		6	1.447		93	22.8		39	1.449		100*	20.6		32
36	N.A.		63	22.3		5	1.460		100*	22.4		26	1.471		100*	20.5		35
	* REMOVED FROM CHARGE - DUE TO PRESSURE LIMIT.																	
	** EXCEEDED 1.480 VOLTS DURING CHARGE.																	
	*** FOR CELLS WITH S/N'S 13 TO 24, DATA GIVEN IS SECOND 48 HR CHARGE, DUE TO																	
	INTERUPTION OF INITIAL TEST.																	

END-NADC (SP 11/73)

DEEL/C 74-228

TABLE III
INTERNAL RESISTANCE AND SHORT TEST DATA

9ND-NADC (SP 11/73)

[illegible]

TABLE IV
Charge Efficiency and Overcharge Data

SERIAL NUMBER	Charge Efficiency (20°C)						Overcharge Test (0°C)						Overcharge Test (35°C)					
	END-OF-CHARGE			END-OF-DISCHARGE			END-OF-CHARGE			END-OF-DISCHARGE			END-OF-CHARGE			END-OF-DISCHARGE		
	CELL (Volts)	AUX ELECT (Volts)	PRESS (PSIA)	CAPAC- ITY (ah)	AUX ELECT (Volts)	PRESS (PSIA)	CELL (Volts)	AUX ELECT (Volts)	PRESS (PSIA)	CAPAC- ITY (ah)	AUX ELECT (Volts)	PRESS (PSIA)	CELL (Volts)	AUX ELECT (Volts)	PRESS (PSIA)	CAPAC- ITY (ah)	AUX ELECT (Volts)	PRESS (PSIA)
13	1.379	N/A	5	4.6	N/A	5	1.501**	N/A	17	13.3	N/A	8	1.418	N/A	48	7.9	N/A	15
14	1.379		6	6.1		6	1.503**		19	14.1		10	1.434		51	6.3		15
15																		
17	1.376		8	6.2		8	1.542°		100*	24.8		18	1.404		100 [□]	21.7		39
18	1.376		8	6.2		8	1.535°		100*	24.5		18	1.404		100 [□]	22.3		40
20	1.376		1	5.9		1	1.540°		102*	25.4		15	1.404		100 [□]	22.5		35
21	1.383		5	6.7		5	1.470		19	23.6		11	1.373		44	14.2		15
23	1.385		5	6.6		5	1.473		21	24.2		13	1.379		46	13.7		15
24	1.385		6	6.6		6	1.472		19	24.2		13	1.381		45	14.2		15
25	1.379		4	4.2		4	1.513°		39	27.8		19	1.394		75	22.1		35
27	1.379		6	4.2		7	1.494°		56	26.6		23	1.388		100 [□]	16.2		26
28	1.380		6	4.6		8	1.490°		60	26.2		23	1.385		100 [□]	15.2		22
29	1.376		6	4.8		6	1.491°		27	27.8		12	1.393		85	23.5		31
30	1.376		7	4.9		7	1.497°		25	28.4		14	1.396		69	23.5		31
31	1.376		7	4.9		7	1.490°		31	27.9		15	1.393		86	25.0		36
33	1.383		7	4.9		7	1.492°		47	22.5		19	1.389		89	18.3		45
34	1.385		11	5.3		13	1.511°		101*	17.8		14	1.395		100 [□]	12.4		23
36	1.385		6	5.2		8	1.535°		105*	18.2		17	1.398		100 [□]	12.5		35
*	REMOVED FROM CHARGE DUE TO PRESSURE LIMIT (S/N 17, 18, AND 20 38 AH IN; S/N 34, AND 36, 32 AH IN)																	
**	CELLS EXCEEDED 1.60 VOLTS AT S.O.C																	
□	EXCEEDED 1.520 VOLTS DURING CHARGE. (S/N EXCEEDED 1.560 VOLTS)																	
□	REMOVED FROM CHARGE DUE TO PRESSURE LIMIT (S/N 17, 18, AND 20, 31 AH IN; S/N 27, 28, 32 AH IN; S/N 34, 36, 19 AH IN)																	

SHD-NADC (SP 11/73)

OEEL/C 74-228

TABLE V
PRESSURE VS. CAPACITY TEST DATA

Serial No.	13	14	17	18	20	21	23	24	25	27	28	29	30	31	33	34	36
Start-of-Charge, Press.	1	1	2	2	1	2	3	1	3	3	2	2	3	2	2	2	0
AH in to 5 PSIA	4.2	1.4	32.7	32.8	32.0	5.4	21.9	7.9	28.6	17.6	13.6	26.7	1.8	32.2	17.2	6.7	N.A.
Cell (volts)	1.692	2.352	1.489	1.490	1.476	1.551	1.470	1.496	1.451	1.450	1.478	1.446	1.427	1.465	1.475	1.618	N.A.
Aux (volts) N/A																	
AH in to 10 PSIA	11.5	2.2	34.8	34.8	35.2	8.3	27.8	29.6	35.0	28.9	18.0	34.9	33.6	36.1	24.7	7.9	N.A.
Cell (volts)	1.616	2.295	1.525	1.523	1.516	1.552	1.483	1.485	1.516	1.460	1.479	1.507	1.499	1.512	1.491	1.617	N.A.
Aux (volts) N/A																	
AH in to 15 PSIA	12.7	3.0	35.6	35.5	36.1	10.3	30.4	31.4	35.9	33.3	19.6	36.1	35.5	36.9	27.1	8.7	6.7
Cell (volts)	1.628	2.205	1.544	1.539	1.541	1.551	1.494	1.501	1.547	1.481	1.480	1.536	1.541	1.533	1.508	1.612	1.723
Aux (volts) N/A																	
AH in to 20 PSIA	14.7	3.8	36.0	35.7	36.3	12.7	32.0	32.4	36.1	34.9	23.7	36.6	36.1	37.4	28.6	9.9	7.9
Cell (volts)	1.612	2.106	1.554	1.544	1.545	1.535	1.502	1.510	1.552	1.498	1.481	1.548	1.552	1.545	1.522	1.607	1.709
Aux (volts) N/A																	
AH in to V/L (1.55V)			36.0						36.1				36.1				
Aux (volts) N/A																	
Press (PSIA)			20						20				20				
30 Min OCV, Cell	1.366	1.345	1.410	1.406	1.415	1.366	1.374	1.374	1.399	1.388	1.387	1.392	1.387	1.386	1.381	1.373	1.371
Aux (volts) N/A																	
Press (PSIA)	9	10	27	27	28	17	11	10	22	22	21	22	19	22	21	19	21
1 hour OCV, Cell	1.354	1.337	1.400	1.396	1.402	1.357	1.367	1.367	1.384	1.376	1.366	1.376	1.376	1.376	1.370	1.364	1.361
Aux (volts) N/A																	
Press (PSIA)	6	8	27	27	29	13	10	8	20	22	20	20	18	20	18	18	20
EOD AH out	3.8	.2*	28.5	28.3	28.5	7.6	24.3	25.4	27.8	27.6	16.8	29.2	29.0	29.3	21.8	4.8	3.2
Aux (volts) N/A																	
Press (PSIA)	3	6	20	20	19	4	6	6	11	14	13	13	13	13	11	13	13

* REVERSED ON DISCHARGE, S/N 14 (-7.14 VOLTS)

N.A. = NOT AVAILABLE